CHAPTER 5 STUDY GUIDE PROTOZOAN GROUPS

5.1 Emergence of Eukaryotes and a New Life Pattern

A. **Cellular Symbiosis**
1. The first evidence of life dates to 3.5 billion years ago; these first cells were bacteria-like.
2. The origin of complex eukaryote cells was most likely symbiosis among prokaryotic cells.
3. Aerobic bacteria engulfed by bacteria unable to tolerate the increasing oxygen may have become mitochondria found in most modern eukaryotic cells.
4. Engulfed photosynthetic bacteria evolved into chloroplasts; descendants in the green algae lineage gave rise to multicellular plants.
5. Protozoa are a diverse assemblage with mixed affinities.
   a. They lack a cell wall.
   b. They have at least one motile stage in the life cycle.
   c. Most ingest their food.

B. **General Features**
1. Over 64,000 species are named; half are fossils.
2. Although they are unicellular organisms, protozoan cell organelles are highly specialized.
3. They are ecological diverse, widely dispersed, but many are limited to narrow environmental ranges.
4. They can be fantastically numerous, forming gigantic ocean soil deposits.
5. About 10,000 are symbiotic in or on animals or plants; some are human disease agents.
6. Some are colonial, some have multicellular stages.
7. Protozoa have only one non-reproductive cell type and lack embryonic development; embryonic development is one of the criteria for metazoa.

C. **Ancestry (Figure 5.1)**
1. Protozoans carry on all life activities inside a single plasma membrane; they are acellular or **unicellular**.
2. Protozoa were considered one phylum; recent work shows there are at least 7 and possibly more phyla. Some experts would recognize up to 12 new kingdoms after reclassification.
3. **Protista**, which also included unicellular algae, was an even larger paraphyletic group.
4. The term “protozoa” is now used informally without implying phyletic relationship.

D. **Biological Contributions**
1. Protozoa have intracellular specialization or organization of organelles in cells.
2. Cells may have distinct functions; some colonial protozoa have separate somatic and reproductive zooids, therefore a division of labor.
3. Asexual reproduction occurs by mitotic division.
4. Some have true sexual reproduction with zygote formation.
5. Responses to stimuli represent the simplest reflexes and inborn behaviors known.
6. Shelled protozoa have the simplest exoskeletons.
7. Basic enzymes systems support all types of nutrition: autotrophic, saprozoic and holozoic.
8. Many have developed different means of locomotion through adaptation and/or endosymbiosis.

5.2 Form and Function

A. **BOX: Characteristics of Protozoan Phyla (page 92)**
1. They are unicellular with some colonial and multicellular stages.
2. Most are microscopic.
3. All symmetries are present within members of the group.
4. No germ layers are present.
5. No organs or tissues are formed, but specialized organelles serve many of these functions.
6. They include free-living, mutualistic, commensal and parasitic forms.
7. They move by pseudopodia, flagella, cilia and they can direct cell movements.
8. Most are naked, but some have a simple endoskeleton or exoskeleton.
9. All types of nutrition are present: autotrophic, heterotrophic and saprozoic.
10. They can be aquatic or terrestrial, and free-living, symbiotic or parasitic.
11. Reproduction is asexual by fission, budding or cysts; or sexual by conjugation or syngamy of gametes

B. **Nucleus (Figure 5.2)**
1. The nucleus is membrane bound and contains DNA in the form of chromosomes.
2. Nucleoli are often present inside the nucleus and visible during mitosis in ciliates.
3. The presence of nucleoli is a defining characteristic of Euglenoids.

C. **Mitochondria**
1. Organelle use in energy acquisition with oxygen as the final electron acceptor.

2. Cristae form identifies some protozoan clades.
3. Hydrogenosomes are found in cells without mitochondria; they produce molecular hydrogen.
4. Kinetoplasts are also mitochondrial derivatives that work with organelles at the base of flagella.

D. Golgi Appartus

1. Also known as dictyosomes, they are secretory organelles with endoplasmic reticulum.
2. Parabasal bodies are similar structures with similar functions.

E. Plastids

1. Organelles with photosynthetic pigments such as chloroplasts.
2. Though possibly gained by secondary endosymbiosis, they may indicate shared ancestry.

F. Extrusomes

1. Membrane bound organelles extruded from the cell such as trichocysts.

G. Locomotor Organelles

1. **Cilia** and **flagella** are morphologically the same and may both be called undulipodia (Figure 5.3).
2. Cilia propel water parallel to the cell surface; flagella propel water parallel to the flagellum axis.
3. The **Axoneme**
   a. Each contains a "9 + 2" pattern of paired microtubules, the axoneme.
   b. A membrane continuous with the cell membrane covers the axoneme.
   c. The center pair of tubules ends at a small plate.
   d. The **kinetosome**, a short tube of 9 *triplet* microtubules joins at the base of the axoneme.
   e. The kinetosome is same in structure as the centriole and therefore they may give rise to each other.
4. Both protozoan and metazoan flagella and cilia have kinetosomes at their bases.
5. The sliding microtubule hypothesis explains the movement of cilia and flagella.
   a. Chemical bond energy in ATP propels the action.
   b. Release of ATP energy causes filaments to "walk along" an adjacent filament.
   c. Shear resistance causes the axoneme to bend.

H. Pseudopodia (Figure 5.4)

   a. This is chief means of locomotion in ameboid cells, other protozoa, many invertebrates, and vertebrates.
   b. These extensions of the cell contain either a granular endoplasm or nongranual ectoplasm.
   b. **Lobopodia** are large blunt extensions of the cell body containing both endoplasm and ectoplasm (Figure 5.5)
   c. **Filopodia** are thin extensions containing only ectoplasm; these are seen in *Chlamydophrys*.
   d. **Reticulopodia** repeatedly rejoin to form a netlike mesh.
   e. **Axopodia** occur in Actinopoda (Figure 5.6).
      1) Axial rods of microtubules support these long thin pseudopodia.
      2) They form a geometrical array, which is the axoneme of the axopod.
      3) Addition and removal of microtubular material extends and retracts the axopod.
      4) Cytoplasm flows away from the body on one side and toward the body on the other.
   g. **How Pseudopodia Work (Figure 5.7)**
      1) A lobopodium forms by extending ectoplasm as a **hyaline cap**; endoplasm flows into it.
      2) Flowing endoplasm contains actin subunits with proteins that prevent actin from polymerizing.
      3) Endoplasm flows into the hyaline cap, the actinmyosin filaments crosslink forming a semisolid gel.
      4) The endoplasm becomes ectoplasm.
      5) At the posterior end, actin-binding protein releases microfilaments which return to the sol state of endoplasm.

I. Nutrition and Digestion (Figure 5.8)

1. **Autotrophs** synthesize their own food and **heterotrophs** obtain organic molecules made by others.
2. **Phagotrophs** or **holozoic** feeders ingest food particles while **osmotrophs** or **saprozoic** feeders ingest soluble food.
3. *Euglena* is an example of many that use several strategies; few use any one strategy exclusively.
4. Holozoic nutrition uses phagocytosis; the membrane invaginates around a food particle.
5. An enclosed food particle is a food vacuole or **phagosome**.
6. **Lysosomes** fuse with phagosomes and dump enzymes to digest the contents.
7. As digested food is absorbed, the phagosome becomes smaller.
8. In ciliates, the site of phagocytosis is a stable **cytostome**.
9. Many ciliates have a point for expulsion of wastes, the **cytopyge** or **cytoproct**.

J. Excretion and Osmoregulation

1. Excretion of metabolic wastes is by diffusion or emptying of contractile vacuoles.
2. **Contractile vacuoles** fill and empty to maintain osmotic balance (Figure 5.9).
   a. A **proton pump** may actively transport H^+ ions and cotransport bicarbonate into the vacuole followed by water.

b. The vacuole membrane would fuse with the cell membrane thereby releasing water and ions to the outside.

K. Reproduction

1. Asexual Processes
   a. **Fission** produces more individuals than other forms of reproduction; binary fission is most common and produces two identical copies (Figure 5.10).
   b. Budding occurs when a small progeny cell pinches off from a parent cell, and seen in some ciliates.
   c. **Multiple fission**, or **schizogony**, undergoes several nuclear divisions followed by cytokinesis causing many simultaneous individuals to form at once; it is common in Apicomplexa
   d. If union of gametes precedes multiple fission, it is called **sporogony**.
2. Sexual Processes
   a. Although some protozoa are exclusively asexual, sex is a widespread and important source of genetic variation.
   b. Like metazoa, some protozoa undergo **gametic meiosis**: meiosis occurs before gamete formation.
   c. In some flagellates and Sporozoea, the first divisions after fertilization are **zygotic meiosis**; all individuals produced up to next zygote are haploid.
   d. Some foraminiferans show an alternation of haploid and diploid generations or **intermediary meiosis**, as in many plants.
   e. Fertilization of one gamete by another is **syngamy**; this is the standard form of sexual reproduction.
   f. **Autogamy** is when gametic nuclei arise by meiosis and fuse to form a zygote inside the parent organism.
   g. **Conjugation** is exchange of gametic nuclei between paired organisms, common in *Paramecium*.
3. Encystment and Excystment
   a. Protected only by a delicate membrane, protozoa are successful in changing and harsh environments.
   b. Cysts are dormant forms that shut down metabolism and have a resistant material covering.
   c. Encystment is not found in *Paramecium*, some parasitic forms, and some marine forms.
   d. Cysts often resist cold or hot temperatures; some tolerate acidity but not sunlight.
   e. Some protozoa form cysts as a stage in a regular life cycle; most form cysts due to a change in environment.
   f. During encystment, cilia or flagella are resorbed; the Golgi apparatus secretes the cyst wall.
   g. Under favorable conditions, the organism escapes from the cyst; parasitic forms cue on host stimuli.

4.3 Protozoan Taxa

Clades are easily recognized by features such as netlike pseudopodia, flattened mitochondrial christae, colony formation, and flagella.

A. Viridiplantae

1. **This clade contains unicellular and multicellular green algae, bryophytes, and vascular plants.**
2. **Chlorophylls a and b are found in their chloroplasts.**
3. **A subset of this clade, the green algae are placed in the phylum Chlorophyta.**

B. Phylum Chlorophyta

1. "Plantlike" protozoa such as the flagellated, single-celled algae (e.g., *Chlamydomonas* and colonial forms such as *Gonium* (Figure 5.11).
2. Contain one or more characteristic chloroplasts.
3. Colonial forms include *Volvox* (Figure 5.12).
4. In *Volvox*, a number of asexual generations may follow before sexual reproduction occurs .

C. Phylum Euglenozoa

1. Recognized as a monophyletic group based on presence of nucleoli and dicoid mitochondria.
2. Possesses a series of longitudinal microtubules that stiffen the membrane into a **pellicle.**
3. *Euglena* (Figure 5.13) contains chloroplasts with chlorophylls *a* and *b* along with a light-sensitive **stigma.**
4. Euglenozoa also contains Kinetoplasta—all parasitic in plants and animals with a unique organ, the **kinetoplast** (part of their mitochondrion).
5. *Trypanosoma brucei* cause two forms of African sleeping sickness and nagana in cattle.
6. *Trypanosoma cruzi* causes Chagas' disease in Central and South America.

D. Phyla Retortamonada and the Diplomonads

1. This phylum has been divided into two clades: Retortamonads and Diplomonads.
1. Lack mitochondria due to a secondary loss after branching from the eukaryotic lineage.
2. *Giardia* (Figure 5.10) is a common intestinal parasite of humans causing diarrhea.

E. Parabasalids

3. This clade contains members of the phylum Axostylata that contain an **axostyle** rod composed of microtubules.
4. Members of class Parabasalea also have a **parabasal body** (a Golgi apparatus connected by a fiber to one of the kinetosomes).

5. Members of the order Trichomonadida possess **hydrogenosomes**—organelles analogous to mitochondria but which produce molecular hydrogen when oxygen is absent.
6. *Trichomonas vaginalis* causes vaginitis in females, but produces no symptoms in males.

F. Superphylum Alveolata

1. Contain three phyla: Apicomplexa, Ciliophora, Dinoflagellata.
2. Alveolates possess alveoli or related structures (membrane-bound sacs that lie beneath the cell membrane that produce pellicles in ciliates and thecal plates in dinoflagellates).

G. Phylum Ciliophora

1. Ciliates are the most diverse and specialized of the protozoans, usually solitary and motile (Figure 5.14).
2. Ciliate Structures
   a. They are always multinucleate with at least one macronucleus and a micronucleus.
      1) Macronuclei are responsible for metabolic and developmental functions.
      2) Micronuclei participate in sexual reproduction and give rise to macronuclei afterwards.
      3) Micronuclei divide mitotically and macronuclei divide amitotically.
   b. The **pellicle** varies from a simple membrane to thickened armor.
   c. Cilia
      1) Cilia are short and often arranged in longitudinal or diagonal rows.
      2) Cilia may be fused into a sheet, an **undulating membrane**, or smaller **membranelles** to propel food to the **cytopharynx**.
      3) Fused cilia form stiffened tufts called **cirri**, used in locomotion.
      4) A structural system of fibers, the **infraciliature**, is beneath the pellicle (Figure 5.16) but it does not coordinate movement.
      5) Movement appears coordinated due to waves of depolarization of the cell membrane.
      6) Ciliates have trichocysts and toxicysts at the bases of cilia that expel threadlike structures for defense or capturing prey when stimulated (Figure 5.15)
      7) Most ciliates are holozoic; they have a mouth (cytostome) sometimes with specializations for feeding.
      1) Other common ciliates include *Stentor*, *Vorticella* and *Euplotes*
      2) *Didinium* frequently attacks *Paramecium.*
      10). Contractile vacuoles are feed by connecting canals and act as osmoregulatory organelles (Figure 5.16).
3. Reproduction and Life Cycles
      1) **Asexual binary fission** occurs across kineties (ciliary rows); the micronucleus divides and the macronucleus elongates and divides (Figure 5.17).
      2) **Conjugation** is temporary union of two individuals; the macronucleus disintegrates and the micronucleus undergoes meiosis where one of four haploid micronuclei divides and one is exchanged (Figure 5.18).

D. Phylum Dinoflagellata

1. Examples
   a. Formerly included with the Sarcomastocophora, many are photoautotrophic.
   b. Some species are among the most important primary producers in marine environments
   c. Two flagella (one equatorial, one longitudinal) (Figure 5.19).
   d. Body may be naked or covered by cellulose plates.
   e. Can ingest prey through a mouth region.
   f. *Noctiluca* is a voracious predator capable of bioluminescence.
   g. Zooxanthellae are dinoflagellates that live as mutualists within certain protozoa, sea anemones, horny and stony corals, and clams.
   h. Some produce "red tides" through algal "blooms" with considerable economic loss to the shellfish industry.
   i. *Pfiesteria pisicida* releases a toxin that stuns fish.

I. Phylum Apicomplexa

1. All are endoparasites; hosts are in many animal phyla.
2. An apical complex is a feature of this phylum; it is present only in certain stages.
3. Rhoptries and micronemes help it penetrate the host's cells.
4. Pseudopodia occur in some stages; gametes may be flagellated and contractile fibrils may form waves to propel it through liquid.
5. The life cycle usually includes both sexual and asexual stages; an invertebrate may be an intermediate host.
6. At some point, they form a spore (oocyst) that is infective in the next host.

7. Coccidians infect both vertebrates and invertebrates; gregarines infect invertebrates.
   a. **Plasmodium: The Malarial Organism Life Cycle** (Figure 5.20)
      1) Malaria is the most important infectious disease of humans.
      2) *Anopheles* mosquitoes carry all forms; the female injects sporozoites from *Plasmodium* in her saliva.
      3) **Sporozoites** penetrate liver cells and initiate schizogony.
      4) Merozoites are released from the liver, enter red blood cells and become trophozoites.
      5) The trophozoite in a red blood cell undergoes schizogony, producing 6-36 merozoites that burst forth to infect more red blood cells.
      6) This cyclic release of foreign substances produces the chills and fever of malaria:
      7) After some cycles of schizogony, some merozoites produce **microgametocytes** and **macrogametocytes**.
      9) Gametocytes in blood are ingested by mosquitoes and mature into gametes that fertilize in the insect gut.
      10) The zygote becomes a motile **ookinete** that penetrates the stomach wall of the mosquito and becomes an **oocyst**.
      11) The oocyst undergoes sporogony and thousands of **sporozoites** are produced; these migrate to the mosquito's salivary gland where they are injected into a human host.
      14) Elimination of mosquitoes and breeding places is difficult; insecticide resistance by mosquitoes and drug resistance by *Plasmodium* will allow this to be a serious disease for a long time.

   b. *Toxoplasma* in Cats and Humans
      1) This parasite is found in cat intestines; extraintestinal stages develop in other mammals.
      2) Toxoplasma in humans causes few ill effects except in AIDS patients or pregnant women.
      3) More than 20% of all adults in the United States are infected with *Toxoplasma gondii*.
      4) Cryptosporidium parvum causes diarrheal disease worldwide.

J. Amebas (Ameboid organisms)

1. Amebas (Ameboid Organisms)
   a. *Amoeba proteus* is most commonly studied.
   b. Move by means of pseudopodia.
   c. The cell membrane encloses the ectoplasm and endoplasm.
   d. The nucleus, contractile vacuole and vesicles can be seen by microscope.
   e. Ameba are holozoic: feed on algae, protozoa, rotifers, etc., by **phagocytosis** surrounding food with a pseudopod.
   f. Reproduction is by binary fission; sporulation and budding also occur.
   g. *Entamoeba histolytica* lives in the human large intestine and attacks the intestinal wall with enzymes, causing severe and often fatal diarrhea.
   h. **Foraminiferans** are shelled forms found mainly in oceans; that secrete many chambered tests of calcium carbonate (Figure 5.21)
   i. **Radiolarians** are marine forms, with intricate siliceous skeletons that do not form a monophyletic group (Figure 5.22)

2. How Do We Classify Amebas?
   a. Classification based in part on characteristics of their pseudopodia and whether or not they have a protective **test.**
   b. Previously grouped together in Sarcodina, this was a polyphyletic taxon.

3. Nonactinopod Amebas
   a. These amebas form lobopodia, filopodia, or rhizopodia.
   b. *Acanthamoeba* forms lobopoda, *Chlamydophrys* forms filopodia.
   c. *Entamoeba histolytica*, a rhyzopodia, causes amebic dysentery in humans.

4. Actinopod Amebas
   a. A polyphyletic group with axopod pseudopodia containing some radiolarians.

5.4 Phylogeny and Adaptive Radiation

A. Phylogeny

1. Traditionally, amebas (former Sarcodina) and flagellates (former Mastigophora) were considered to be separate classes.
2. However, some "flagellates" can form pseudopodia, and some amebas had flagellated stages.
3. Recent analyses of gene encoding the small subunit of ribosomal RNA have shown that neither Sarcodina nor Mastigophora are monophletic groups
4. Ameboid forms arose independently many times.
5. New information strengthens the hypothesis of a symbiotic origin of eukaryotes.

6. The common ancestor of green plants and green algae acquired its chlorophyll-bearing plastids by symbiogenesis with a cyanobacterium.
7. In Euglenozoa the acquisition of their plastids apparently occurred after divergence from ancestors of Kinetoplasta.
8. Apicomplexans have a small circular, plastid-like DNA, localized to a discrete organelle surrounded by four membranes, and evidently a relict plastid inherited from their common ancestor with dinoflagellates.

B. Adaptive Radiation

1. Ameboid forms have radiated into a wide range of environments and have become morphologically diverse.
2. Flagellated forms have adapted to a wide range of habitats and have great variation.
3. Specialization is most advanced in ciliates and intracellular parasitism in Apicomplexa.

C. Classification:

1. Phylum Chlorophyta
2. Phylum Retortamonada
  a. Class Diplomonada
11. Phylum Axostylata
  a. Class Parabasalea
12. Phylum Euglenozoa
  a. Subphylum Euglenida
    1) Class Euglenoidea
  b. Subphylum Kinetoplasta
    1) Class Trypanosomatidea
2. Phylum Apicomplexa
  a. Class Gregarinea
  b. Class Coccidea
2. Phylum Ciliophora
3. Phylum Dinoflagellata
4. Amebas
  a. Rhizopodans
  b. Granuloreticulosans
  b. Actinopodans